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Title of Grant: Quantification of changes in thermospheric O/N₂ from observations of UV airglow and aurora

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Proposed Objectives

The primary goal of the proposed research was to use images from the Ultraviolet Imager (UVI) as remote monitors of changes in the ratio of thermospheric O to N₂ at high latitudes in response to geomagnetic disturbances. The principal project tasks were to select UVI image data, develop and extend modeling/analysis tools, and, finally, correlate observed changes with geomagnetic activity. In particular, it was necessary to model the average expected dayglow surface to isolate changes from storms. Note that this research differs significantly from previous efforts in that the 'quiet-time' dayglow surface is modeled from first principles rather than being developed empirically from observations. This technique should thus be more generally applicable to observations from other missions.

Accomplishments

The principal accomplishments of the funded research were 1) the development of a new set of comprehensive line-of-sight (LOS) modeling tools and 2) a series of sensitivity studies which explored the relative importance of physical factors in quantitative analysis of FUV auroral images.

1. LOS Model Development

Initially, two tools were available to model airglow: the Field Line Interhemispheric Plasma (FLIP) model and a two-stream auroral deposition code that includes photochemical sources. These models calculate volume emission rates as a function of altitude that can be integrated to produce vertical column brightnesses. At the start of funded research, no method existed for modeling images along arbitrary lines of sight. Therefore, one of the first tasks was to develop a simple photochemical model (referred to henceforth simply as the airglow model) tailored to perform calculations along given lines-of-sight (LOS) within the UVI field of view.

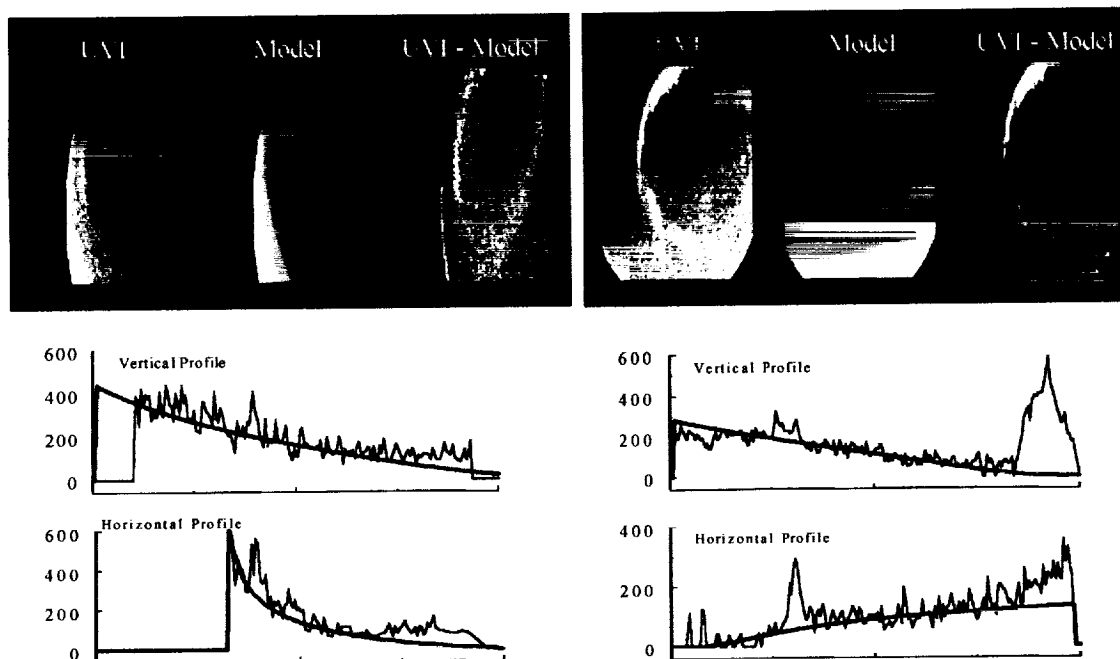


Figure 1. Airglow modeling and removal using LOS modeling tools (from [Germany *et al.*, 1999b]).

The accuracy of the airglow model was compared with the other two more comprehensive models (FLIP and 2-stream model). Vertically-integrated column brightnesses from the airglow model matched those of the other two models to within 16%. This was deemed sufficiently accurate for initial efforts to compare UVI airglow observations with results from the airglow model. In particular, mid-low-altitude (2-4 Re) nadir-viewing dayglow images were examined. These were chosen because they are not contaminated with aurora and are basically flat, without edges or large slant path changes across the field of view. Since UVI data included the ascending phase of the current solar cycle, it was possible to examine dayglow for a range of solar EUV inputs.

As expected, both observations and modeled emissions respond basically linearly with changes in F107 [Germany *et al.*, 1999b]. (F107 values for the examined period were less than 200 and thus avoided the 'saturation effect' noted at higher F107.) However, systematic differences between model and observations were found. These differences were seen across all filters, with the contamination door/window open or closed, and for all viewing conditions. These differences can be due to changes in instrumental calibration, in data processing errors, or in modeling errors. With respect to the latter possibility, note that all three modeling tools agree within 16% and also show excellent agreement with other models within the community. Furthermore, the differences are seen for both the molecular nitrogen emissions and atomic oxygen emissions, as well as for emissions that are absorbed strongly by O₂ and those that are not. Each of these mechanisms employ separate algorithms that cannot individually

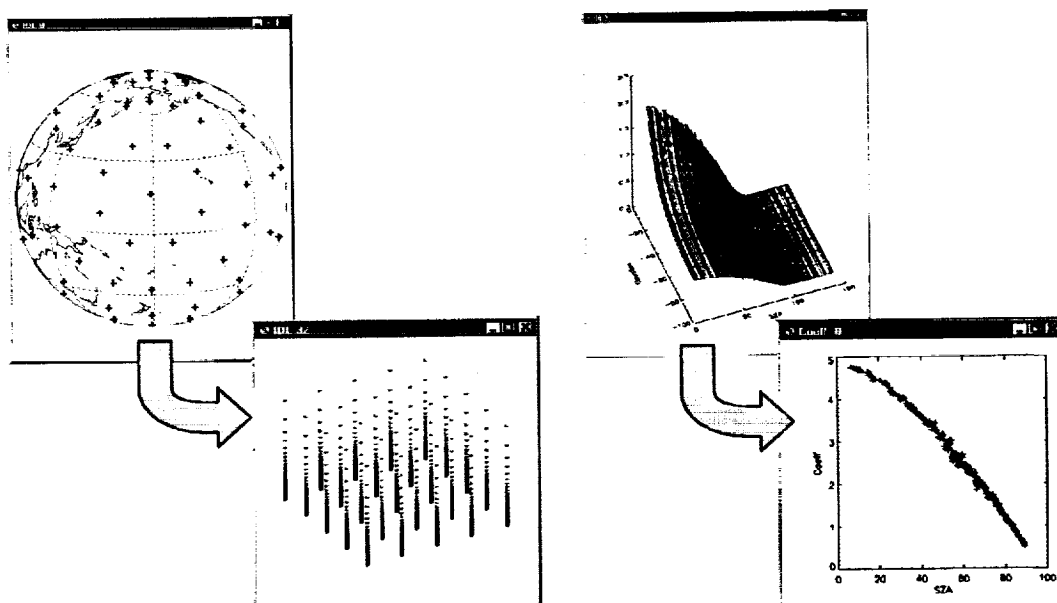


Figure 2. 3-D geometry and parametric fitting used in LOS models (from [Germany *et al.*, 2000]).

account for the differences seen.

Regardless of the source of the differences between model and observations, by quantifying these differences as a function of solar zenith angle it was possible to derive a correction function from the low-altitude nadir viewing cases. A critical test of the validity of the correction function (derived from low-altitude, low-latitude observations) is its application to high-altitude, non-nadir viewing cases which include a large range of solar zenith angle and spacecraft look angle, including limb viewing cases, and auroral emissions. Comparisons for two cases are shown in Figure 1.

As can be seen, the derived correction function did an excellent job of matching observed airglow surfaces, doing as good a job, or better, than airglow estimates based on empirical sampling methods currently in use by the UVI team. Subtraction of the modeled airglow left behind a clean image of the auroral emissions, even in the case of dim aurora.

Because of difficulties with the original airglow model scheme, a more accurate and efficient line-of-sight airglow calculation scheme was developed. In the original airglow model the calculations were data driven, i.e., a single UVI image was selected and essentially all pixel lines of sight were modeled for comparison. Selecting another image, even one nearly simultaneous with the original, required redoing the dayglow pixel calculations. This cumbersome system was replaced with a model-driven scheme in which vertical profiles are calculated using the photochemical scheme of the two-stream code. (The original airglow model was abandoned.) Vertical profiles are

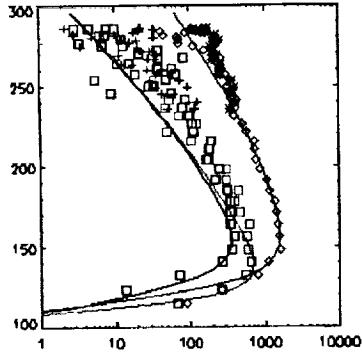


Figure 3. Emission profiles for LBH (red) and OI 1356 (blue). Symbols: Rocket data from S. Bailey; Lines: LOS model.

calculated for the full dayglow surface for the day of interest. These are then combined into a three-dimensional data volume (Figure 2). Image analysis now requires only interpolation of pixel lines of sight through this modeled data volume, a much faster that allows data mining techniques to be used with UVI data. The next stage of development was to incorporate the 'pierce-point' approach of *Strickland et al.* [*Appl. Opt.*, 33 (16), 3578-3594, 1994] which precalculates not only volume production rate data, but line-of-sight integrations for each node point as well. This enhancement removed some of the slowest calculations from the data analysis process and allowed examination of even larger data sets.

This line-of-sight calculation method was used to compare rocket FUV observations provide by S. Bailey with our models (Figure 3).

Excellent agreement is seen in the shape of the profiles. However, all the emission data had to be scaled by 0.6, which may be reasonable for the atomic oxygen emissions, but is not for the LBH. Initial model runs by S. Bailey agreed with our modeling, which indicates that further analysis of the rocket data needs to be performed. Unfortunately, it was not possible to explore this in more detail due to S. Bailey's other commitments.

In addition to work with the airglow models, several analysis tools were developed, including the ability to transform airglow images as functions of solar zenith angle and instrument look angle (angle between the instrument LOS and the local vertical). In addition, tools were developed that 'mine' through volumes of UVI image data,

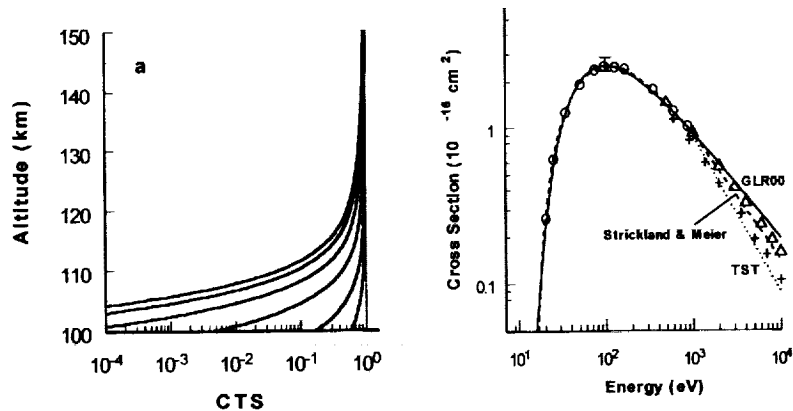


Figure 4. Left: Impact of O_2 absorption as a function of altitude and wavelength. Right: High energy variation in total ionization cross sections. (From [*Germany et al.*, 2001].)

comparing modeled dayglow emissions with UVI observations for each of the three principal UVI filters: 1356, LBHL and LBHS. These tools enabled searches of large quantities of UVI images.

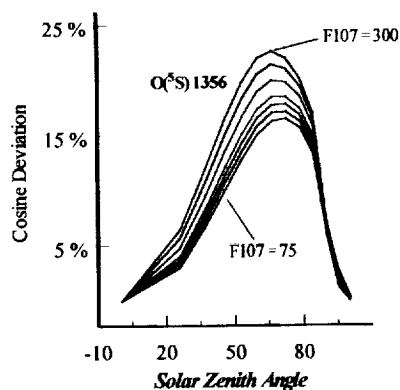


Figure 5. Percent difference between simple cosine airglow function and a more detailed parameterization developed under this grant.

2. Sensitivity Studies

In addition to model development, a series of sensitivity studies was conducted to better understand the impact of different physical processes on FUV auroral emissions. *Germany et al.*, [1999b] explored issues that can impact quantitative analysis of UVI images, including detector degradation and background contamination, and demonstrated that observed UVI dayglow surface morphology and dependence on EUV forcing could be accurately modeled.

In additional studie, *Germany et al.*, [2001; 1999a] examined a potentially worrisome issue in auroral analysis by performing a sensitivity study on one of the central cross sections used in the auroral energy degradation calculations. The concern was that since auroral energy estimations are based on relative O_2 absorption, and the resultant attenuation changes exponentially within a narrow altitude region, slight uncertainties in the modeled peak emission height could translate into significant changes in the energy estimates. This is illustrated by the left panel in Figure 4, from *Germany et al.*, [2001]. The column transmission to space (CTS) is shown as a function of wavelength and altitude. For some LBH emissions the absorption changes by over an order of magnitude within 5 km. Thus any uncertainty in modeling the height of a modeled emission can conceivably translate into significant emission changes. To test these effects, the modeled emission height was perturbed by changing the total ionization cross section of N_2 . By varying the total ionization cross section over a range covering available measurements, *Germany et al.*, [2001] showed that the largest expected impact on energy determinations would be about 25%.

Parameterizations are preferable to detailed calculations in situations that involve large numbers of images. The dayglow surface is commonly modeled with a cosine function, which works well near the subsolar point. However, at larger solar zenith angles, we have found deviations on the order of 20-25% between a simple cosine function and our more accurate parameterization (Figure 5). This can be significant since combined auroral/dayglow studies commonly include terminator, i.e. large solar zenith angle, conditions. We also modeled local time effects which are especially significant for 1356 dayglow studies.

Summary

While we did not accomplish our primary science goal of studying compositional changes as a function of solar cycle, significant progress was made in developing the complex LOS modeling utilities needed for compositional analysis. In addition, we now understand the quantitative issues of airglow analysis in auroral FUV images better than before. Finally, the research done under this grant enabled the PI to successfully lobby for additional observational time from the Ultraviolet Imager investigation. Prior to this work UVI operations used the oxygen filters (necessary for aeronomy and compositional studies) sparsely or not at all for periods of up to six months. Citing the research under this grant, the PI was able to obtain use of oxygen filters for approximately 20% of the time. Recently, this figure was increased to 50%. With this change in operations, the knowledge obtained from the science studies, and the extended software development we are better positioned now than ever before to pursue compositional studies. Other researchers have indicated an interest in continuing these studies. The PI has pledged his support for these projects, and looks forward to applying the tools and knowledge from this project in future efforts.

Publications and Presentations

- Germany, G.A., D. Lummerzheim, and P.G. Richards, Impact of Model Differences in Quantitative Analysis of FUV Auroral Emissions: Total Ionization Cross Sections, *J. Geophys. Res.*, 106, 12,837-12,843, 2001.
- Germany, G.A., P.G. Richards, J.F. Spann, M. Brittnacher, and G.K. Parks, Remote sensing of atomic oxygen column densities with UVI images, *EOS Trans. AGU, Spring Meet. Suppl.*, 81, S339, 2000.
- Germany, G.A., D. Lummerzheim, P.G. Richards, J.F. Spann, M.J. Brittnacher, and G.K. Parks, Impact of model differences in quantitative analysis of FUV auroral emissions: Total ionization cross sections, *EOS Trans. AGU, Spring Meeting Suppl.*, 80, F884, 1999a.
- Germany, G.A., P.G. Richards, J.F. Spann, M.J. Brittnacher, and G.K. Parks, Issues in quantitative analysis of Ultraviolet Imager (UVI) data: Airglow, *EOS Trans. AGU, Spring Meeting Suppl.*, 80, S292, 1999b.
- Germany, G.A., W. Swift, P.G. Richards, G.K. Parks, M. Brittnacher, R.K. Elsen, and J.F. Spann, Changes in thermospheric O/N₂ derived from UVI auroral images, *EOS Trans. AGU, Fall Meet. Suppl.*, 78, F526, 1997. (Though not technically part of the funded work, this presentation was done in anticipation of funding and established the techniques used in subsequent work.)